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Geology of the Carswell Structure, Central Part

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by C. T. Harper

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Foreword

The geology of the Carswell Structure is currently of considerable interest due to its probable meteorite impact origin and the presence of the Cluff Lake uranium orebodies. This report, which deals mainly with the basement core rocks of the structure, is one of a series of reports resulting from a four-year program of geoscience surveys under the terms of the Canada-Saskatchewan Agreement on Mineral Exploration and Development in Northern Saskatchewan. This program was supported by funds provided by the federal Departments of Energy, Mines and Resources (25 percent) and Regional Economic Expansion (25 percent) and by the Province of Saskatchewan (50 percent). As this is not part of the sheet report series, only brief geological notes are given.

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August, 1981

Abstract

The Carswell Structure, located about 140 km south-southwest of Uranium City, consists of an uplifted basement core of Archean and/or Aphebian high-grade metamorphic rocks surrounded by inner and outer rings of deformed but unmetamorphosed Athabasca Group sediments. These notes and the accompanying map deal mainly with the geology, structure and mineralization of the basement core, which hosts the Cluff Lake uranium deposits. The crater-like morphology of the structure, the presence of polymict breccias of volcanic aspect (Cluff Breccia) and the occurrence of shock metamorphic features provide evidence of formation by meteorite impact.

Harper, C.T. (1981): Geology of the Carswell Structure, central part; Saskatchewan Mineral Resources, Report 214.

Introduction

The Carswell Structure is located about 440 km northwest of La Ronge and 140 km south-southwest of Uranium City; the area is accessible by an all-weather gravel highway from Buffalo Narrows.

Field work was carried out during the summers of 1976, 1977 and 1978 with funds provided under the Canada-Saskatchewan Agreement on Mineral Exploration and Development in Northern Saskatchewan.

Maximum relief in the area is 70 m, with major topographic variation being largely controlled by bedrock geology; however, local physiographic features are dominated by glacial deposits, including moraine, drumlins, eskers and outwash. Glacial lineaments indicate a southwesterly direction of ice movement. Ventifacts, sandblast polishing and fluting of outcrops, and narrow linear sand dunes attest to periglacial eolian action by strong southeasterly winds.

General Geology

The multi-ring Carswell Structure, 35 km in diameter, is fault bounded and surrounded by essentially undisturbed, flat-lying strata of the Paleohelikian Athabasca Group. The structure consists of a core of high-grade metamorphic rocks of Archean and/or Aphebian age, rimmed by inner and outer rings of deformed but unmetamorphosed Athabasca Group rocks (Currie, 1967; AMOK, 1974; Ramaekers, 1980).

The uplifted basement core, approximately 18 km across, comprises granitic to dioritic, quartzofeldspathic and pelitic gneisses, minor mafic rocks, lean iron formation and granite pegmatites (Harper, 1977, 1978). The basal Athabasca Group and underlying paleoweathered basement (regolith) outcrop locally, in both normal and inverted sequence. The margin of the core is in places faulted tangentially and in turn truncated and offset by radial faults.

The 5 to 8 km wide inner ring comprises conglomerates and sandstones of the William River Subgroup of the Athabasca Group, which are moderately to vertically dipping and in many places overturned. Arcuate airphoto lineaments are interpreted as concentric thrust faults which probably cause stratigraphic repetition. Isolated blocks of basement gneiss, possibly thrust slices, also occur in this zone.

The 3 to 6 km wide outer ring is a down-faulted annular depression dominated by ridges of the Carswell Formation (Athabasca Group), comprising bedded dolomites which are locally stromatolitic, oolitic and brecciated (Currie, 1967). Conformably underlying are interbedded siltstones, shales and fine-grained sandstones of the Douglas Formation (AMOK, 1974). These formations, which in turn conformably overlie the sandstones and conglomerates of the Tuma Lake Formation, are unique to the Carswell Structure. The outer ring is characterized by arcuate faults along which the rocks are drag folded and locally overturned (Raemaekers, personal communication, 1981). Tangential or circular faults which bound the outer ring are themselves truncated and offset by radial faults, and by regional faults unrelated to the structure (see index map).

The basement and William River Subgroup within the core are intruded by the polymict Cluff Breccia (Currie, 1967) of volcanic aspect, believed to have been produced by hypervelocity meteorite impact (Robertson and Grieve, 1975) in Ordovician times (Currie, 1967). The crater-like morphology of the structure, as well as features of shock metamorphism including deformation lamellae in quartz, shatter cones in the metamorphic rocks, pseudotachylite, and shattered cobbles and boulders in basal conglomerates of the William River Subgroup, all support the meteorite impact hypothesis (Currie, 1967; AMOK, 1974; Harper, 1977, 1978; Pagel, 1975; Tapaninen, 1975, 1976).

Basement Rocks

Bedrock exposure is less than one percent and, while the more resistant rock types (granitoids and quartzofeldspathic gneisses) outcrop, the others are generally seen only in trenches, road cuts and diamond-drill core. The major basement rock types are typically interlayered and locally contain up to 60 percent granite (anatectic) pegmatite.

Granodiorite gneiss (G) with lesser amounts of diorite (Ga), felsic gneiss (Gb) and granitic pegmatite together comprise a 'granodiorite complex'. Contacts with the host gneisses are not exposed. The granodiorite gneiss (G) is typically pinkish grey to red on both fresh and weathered surfaces, medium grained (1 to 5 mm) and well foliated, and contains up to 15 percent biotite and/or hornblende which is partially altered to chlorite. Feldspars and up to 30 percent blue to grey quartz are other major constituents. The reddish colouration of the rock derives from finely disseminated hematite in potassium feldspar and, to a lesser extent, in plagioclase. Diorite gneiss (Ga) is darker grey in colour, contains more hornblende and is medium grained (3 to 5 mm). Major constituents are plagioclase (60 to 70 percent) and hornblende (30 to 40 percent). Small amounts of pyrite and pyrrhotite occur disseminated throughout these rocks. The felsic gneisses (Gb) are generally fine grained ($\leq$1 mm), equigranular, granoblastic and composed predominantly of quartz (30 to 40 percent), feldspars (50 to 60 percent) and biotite (0 to 10 percent). Locally these gneisses contain thin mafic layers; in some instances, alternating leucocratic and

melanocratic segregation layering is developed on a 1 to 10 cm scale.

Quartzofeldspathic gneisses (Q) comprise interlayered metaquartzites, feldspathic metaquartzites, meta-arkoses and pelitic gneisses. They are generally light to dark grey to pinkisn grey, fine grained and equigranular granoblastic, and contain up to 10 percent biotite and locally abundant garnet, sillimanite, cordierite, graphite and pyrite. Limonite staining is widely distributed, although pyrite is not always present. The quartz in these rocks (50 to 80 percent) is typically grey to blue in the eastern part of the core area and colourless to white in the western part. Feldspars, commonly displaying argillic alteration, are the other major constituent (20 to 40 percent). Layering is typically developed on a 1 to 5 cm scale, although granite segregations may be several tens of centimetres to several metres in thickness.

A number of divisions are recognized within this unit. Heavily limonite-stained, graphitic, pyritic, garnet-cordierite-biotite (± sillimanite) gneiss (Qa) occurs south and southeast of Claude Lake*, in the OP and D zones, and extending from the eastern margin of the N zone to the F occurrence. These pelitic gneisses are generally medium grained (2 to 5 mm) and light to dark green due to the complete alteration of cordierite to yellow-green pinite and the partial replacement of garnet by dark green to black chlorite. Pink colouration is present where there is abundant fresh garnet. In the vicinity of the F occurrence, southeast of the N zone, massive pods of dark blue quartz up to 10 cm across are common. Pyrite as disseminations and locally irregular masses, graphite as millimetre-sized flakes and sillimanite are minor constituents. Medium-grained (2 to 5 mm), well-foliated, grey-green, amphibolitic and locally garnetiferous quartzofeldspathic gneisses (Qb) underlie parts of the Dominique and Claude ore zones. Quartz (30 percent), feldspars (50 percent), hornblende (10 to 15 percent) and garnet (0 to 10 percent) are major constituents. Hornblende and garnet are largely pseudomorphed by chlorite. A zone of garnetiferous, locally sericitic and graphitic quartzofeldspathic gneisses (Qc) is exposed in several pits along the road between 1 and 3 km north of Marianne Lake* and in outcrops located 2 to 3 km east and west of the road. The garnetiferous rock is white to pink on fresh surfaces, medium grained to pegmatitic (2 to 15 mm), well foliated and, where garnets are abundant, spotted in appearance. The garnets, from 1 to 10 mm in diameter and largely pseudomorphed by dark green to black chlorite, form 10 to 20 percent of the rock. A few percent biotite, also replaced by chlorite, may have been present. The interlayered quartz-sericite gneiss contains blue to grey quartz (60 percent), feldspars (20 to 40 percent), sericite/muscovite (0 to 10 percent) and graphite; the graphite occurs in concentrations of up to 10 percent, but commonly comprises less than 5 percent of the rock. A 2 to 3 m thick band of black graphite schist, containing 10 percent pyrite and as much as 50 to 60 percent graphite, outcrops in a pit at the northern exposed limit of the zone.

Pelitic gneisses (B) are typically dark grey to brown, medium grained (2 to 3 mm) and well foliated, and contain biotite (10 to 30 percent), quartz (30 percent) and plagioclase (50 percent). Although poorly exposed, these rocks appear more abundant in the western part of the basement core. A graphite-, pyrite-, garnet-bearing variety (Ba) is rusty brown in colour and contains considerable interlayered white pegmatite.

Iron formation (IF) outcrops east of Bridle Lake* in association with metagabbro (M) and east-northeast of Louise Lake*. The iron formations are oxide-silicate facies, banded, quartz-magnetite rocks with variable proportions of garnet (10 to 60 percent), biotite (2 to 5 percent), amphibole (10 to 20 percent), pyroxene (0 to 10 percent) and pyrite (0 to 5 percent). Magnetite content varies from 5 to 30 percent and quartz content from 30 to 60 percent.

Metagabbro (M) is a dark green to black, medium-grained (3 to 5 mm), massive to poorly foliated, hornblende (50 to 60 percent) - plagioclase (40 to 50 percent) rock containing 1 to 2 percent disseminated pyrite.

Granite pegmatite (P) is abundant and, in places, comprises as much as 60 percent of Units G, Q and B. It is commonly pink to red, massive, coarse to pegmatitic in grain size (1 to 4 cm) and low in mafic constituents. Major constituent minerals are potassium feldspar (40 to 60 percent), white (locally blue) quartz (40 to 50 percent), plagioclase (0 to 10 percent) and biotite ± muscovite (0 to 5 percent). Garnet crystals, 1 to 2 cm in diameter and commonly pseudomorphed by dark green chlorite, locally form up to 10 percent of the rock. These rocks are interpreted as anatectic segregations and are largely parallel to the lithologic layering.

Cataclastic equivalents of the basement rocks include breccias and mylonites in bands or zones up to several metres thick. Tectonic breccias contain angular, generally aligned fragments of host rocks, commonly less than 2 or 3 cm in size, set in a comminuted groundmass. Chlorite and veins of pseudotachylite are developed in these zones.

The **paleoweathered basement (regolith, h)** underlying the Athabasca Group forms a purple- to maroon-coloured zone, ranging from a few metres to 40 m in thickness, along the margin of the basement core. A thin (10 to 30 cm) ferruginous clay layer locally caps

*Unofficial lake name

*Unofficial lake name

strongly hematized and argillized gneisses in which textures and structures are still preserved. These features, together with the chemical characteristics of the zone, suggest tropical lateritic weathering (Hoeve, 1977; Meillon, 1978).

Athabasca Group

Athabasca Group rocks immediately surrounding the basement core belong to the generally conglomeratic William River Subgroup (W) (Ramaekers, 1980). Clasts vary from less than a centimetre to as much as 30 cm in maximum dimension and are typically hematite-stained quartz, although a few granitic and regolith clasts are also present. Fine to coarse, buff to pinkish sandstone and maroon-coloured shales/siltstones are interbedded. Conglomeratic lenses decrease in thickness and clast size, and grade upward into white, fine-grained, massive sandstones away from the basement contact. The Athabasca Group is strongly brecciated, crushed and altered in places adjacent to the basement unconformity.

One outcrop of **Douglas Formation (D)** occurs about 2 km east of Cluff Lake. It exposes purple and green, finely laminated siltstone interlayered, on a 2 to 5 cm scale, with white to pink, fine ($\leq$0.25 mm) quartz sandstone.

Outcrops of **Carswell Formation (C)**, located west of Cluff Lake, are buff to dark grey and include finely laminated, cryptocrystalline, micritic and stromatolitic dolomite, with the algal mats being up to 0.5 m across and 20 cm thick.

Cluff Breccia

Cluff Breccia (CB), comprising varicoloured, polymict impact breccias, suevite, pseudotachylite and kärnäite, forms veins, dykes and other bodies from a few millimetres to a few tens of metres thick and up to several hundred metres long. Clasts, ranging in size from microscopic to tens of centimetres across, are predominantly of basement rock types and only rarely of Athabasca Group sandstones. The smaller dykes commonly have a higher clast to matrix ratio; in some of the dykes, the clasts increase in size and abundance toward the dyke centre, whereas in most there is no zoning. The pseudotachylite matrix is commonly devitrified, weathering to a greyish green, soft material. Larger bodies of Cluff Breccia may contain primary volcanic structures such as columnar jointing, vesicles, amygdules, flow lines, quartz phenocrysts, perlite and microlites. These rocks are thought to represent remnants of melts resulting from, and invading fractures immediately after, meteorite impact.

Structure

Rocks of the basement core are strongly deformed and metamorphosed to upper amphibolite - lower granulite facies (Herring, 1976). Metamorphism was accompanied by extensive anatexis. Four phases of deformation, designated D_1 through D_4, are considered responsible for the present structural configuration.

Phase 1 (D_1) is represented by the dominant foliation (S_1), generally parallel to the original layering (S_0) and defined by a gneissosity, an alignment of biotite flakes and sillimanite needles and an elongation of quartz and feldspar grains, feldspar augen and garnet and cordierite porphyroblasts. Major and minor folds of this age have not been recognized. The anatectic granite pegmatites (P) tend to parallel S_1 and, together with S_1, are tightly to isoclinally folded by Phase 2 (D_2), which shows only a weakly developed axial planar fabric (S_2). D_2 folds are not distinctive in attitude, although many small-scale representatives are inclined and have shallow plunges of less than 30°.

Phase 3 (D_3) is represented by major and minor open folds which refold D_1 and D_2 and are characterized by northerly trending, steeply dipping axial surfaces, variable north- and south-plunging axes and development of an axial plane fracture cleavage.

Phase 4 (D_4) is related to the Carswell meteorite impact event which also affects the Athabasca Group. Structures resulting from this event include widespread cataclastic and brecciation effects, circular and radial faults, shatter cones, deformation lamellae in quartz and feldspar, and inversion of Athabasca Group strata and the sub-Athabasca unconformity (Currie, 1967; AMOK, 1974; Harper, 1977, 1978; Tapaninen, 1975).

The protrusion of the basement gneisses through the Athabasca Group and preservation of the Carswell and Douglas Formations are believed to have taken place by isostatic rebound (of at least 2000 m) and inward directed slumps (of at least 1000 m), respectively, in response to the meteorite impact.

Cataclasis, unrelated to D_4 deformation and represented by faults, breccia zones and mylonites, probably accompanied and outlasted D_3. A similar and correlatable event of late Hudsonian age is recognized in the Beaverlodge region (Beck, 1969). Two major northeasterly trending airphoto lineaments are interpreted as regional faults (see index map), active since the impact event, as they displace the Athabasca Group sinistrally at Carswell Lake and dextrally along the east margin of the Carswell Structure. These faults, along with several apparent radial faults such as the Cluff Lake, Bridle Lake* and Rooster Lake* Faults, were probably reactivated by the impact. Poor exposure limits interpretation of the amount and direction of movement along these faults.

*Unofficial lake name

Metamorphism

The basement rocks are polymetamorphic (Herring, 1976), with peak metamorphic conditions coinciding with D_1 and possibly D_2. Locally, granulite facies metamorphism is indicatd by hypersthene in some assemblages (Herring, 1976), but, throughout most of the basement core, mineral assemblages are typical of upper amphibolite facies and may represent prograde assemblages. Herring (1976) believes that retrograde metamorphism to amphibolite facies has also occurred. The widespread replacement of garnet, biotite and amphibole by chlorite is thought to represent further retrograde metamorphism related to D_3 and the late brittle deformation; however, similar replacement of those minerals by chlorite has also been linked to the pre-Athabasca weathering event (Harper, 1979; Mellinger, 1980). Superimposed on the above are the shock metamorphic features mentioned previously.

Alteration

The basement rocks also show several distinctive alterations: pre-Athabasca weathering, hydrothermal alteration, impact-related alterations and post-impact weathering. Pre-Athabasca weathering affects all rocks of the basement and is characterized by argillic alteration of feldspars and chloritic, hematitic and argillic alterations of mafic minerals. Quartz is essentially unchanged. The character and mineral assemblages of the weathered rocks are typical of weathering under tropical lateritic conditions (Hoeve, 1977; Meillon, 1978).

Following deposition of the Athabasca Group, the entire Athabasca Basin was subjected to a low temperature (160-250° C) hydrothermal event which affected rocks both above and below the unconformity, and locally, where appropriate physicochemical conditions prevailed, coincided with the formation of uranium deposits. Three types of alteration are characteristic of this event: 1) dark green chloritization; 2) red (hematitic) chloritic alteration with accompanying silicification, dolomitization and tourmalinization; and 3) pale green chloritization and silicification (Hoeve and Sibbald, 1978; Hoeve et al., 1980). Generally all three are represented in the Carswell area, where silicification is minor, dolomitization absent and sericitization accompanies or occurs instead of the pale green chloritization.

Weak chloritic and argillic alteration accompanied the meteorite impact event, principally along fractures created by that event. Surface weathering since the impact is most strongly developed in ore zones and in pyrite-bearing metasedimentary gneisses. It is characterized by limonitization of pyrite, pervasive limonite iron staining, weak argillic alteration and a tendency for outcrops to be reduced to rubble.

Geological Evolution

The relative ages of the basement rocks are still uncertain; however, it is believed that the granodiorite gneisses are probably the oldest and the metasedimentary gneisses younger. North and south of the Athabasca Basin, rocks similar to those of the Carswell area are considered to be Archean (Beck, 1969; Koster and Baadsgaard, 1970; Lewry and Sibbald, 1977) and strongly overprinted by the Hudsonian orogeny. In the Carswell area, a preliminary Rb-Sr isochron age of about 2300 Ma (Bell and Blenkinsop, 1980) has been obtained from the granodiorite gneisses, and may represent a cooling age for the Kenoran orogeny as defined by Stockwell (*in* Douglas, 1980). A single K-Ar age determination on biotite from a metasedimentary gneiss yielded a metamorphic cooling age of 1973 Ma (Herring, 1976), corresponding perhaps to an intermediate thermal event between the Kenoran and Hudsonian orogenies. Peak metamorphism appears to correspond with the older date, but may also have reached upper amphibolite grade in the Hudsonian. The possibility that some of the metasedimentary rocks are Aphebian is plausible but not likely.

Following post-Hudsonian erosion and tropical lateritic weathering of the basement, the Athabasca Group was deposited about 1450 Ma (Hoeve et al., 1980; Bell and Blenkinsop, 1980). The widespread hydrothermal event and main periods of uranium mineralization occurred between 1350 and 1000 Ma (Hoeve and Sibbald, 1978; Hoeve et al., 1980). In the Carswell area, dating of D zone material by U/Pb and Pb/Pb methods has yielded ages ranging from 1330 to 234 Ma (Gancarz, 1979), with the main mineralizing event at about 1050 Ma (AMOK, 1974; Gancarz, 1979). A K-Ar age from sericite (pale green alteration) yielded an age of 988 Ma (Herring, 1976), which coincides with the lower limit of the hydrothermal-uranium mineralization event.

The Carswell impact event occurred in Ordovician times, as indicated by K-Ar age determinations on Cluff Breccia which yield an average age of 478 Ma (Currie, 1967). Periodic reactivation of faults has occurred and erosion has continued to the present.

Economic Geology

Uranium deposits in the Cluff Lake area, containing an estimated 19 500 tonnes U, occur at or near the southern edge of the basement core. Two major types of mineralization, distinguishable by their geologic and structural settings and mineral parageneses, have been recognized (AMOK, 1974; Tapaninen, 1975; Harper, 1978). The N-Claude type is characterized by a relatively simple mineral assemblage of uraninite/pitchblende and coffinite with small and variable amounts of graphite and

bituminous material and Fe, Cu, Pb and Mo sulphides. Both the N and Claude orebodies occur within faulted and sheared quartzofeldspathic gneisses. The D-type has a complex mineral assemblage of uraninite/pitchblende, thucholite and coffinite, together with native gold and selenium, gold tellurides, selenides of Pb, Bi, Ni and Co, sulphides of Fe, Cu and Pb, and bituminous material. The D orebody occurs within strongly chloritized siltstones (Harper, 1980) at the base of the Athabasca Group, as well as in altered and faulted regolithic quartzofeldspathic and pelitic gneisses 'above' the inverted unconformity.

Several smaller deposits are present in this same area; the OP, immediately north of the D, may be in part of the D-type, whereas the R deposit and the F and Dominique occurrences are of the N-Claude type. Both the F and Dominique are associated with inliers of basal Athabasca Group sediments.

Uranium mineralization (presently subeconomic) is found in pelitic gneisses near Bridle Lake*, southeast of Bulidog Lake* (A6 zone) and in several showings east of Bulldog Lake*. Of these, the A6 zone appears to have the best potential, as it is located at the unconformity. Sporadic uranium-thorium mineralization, similar to that at Suzy Lake*, occurs in granodiorite gneisses; grab samples assayed 0.83 percent U_3O_8 and 0.24 percent Th. Two types of radioactive occurrence are present in the Athabasca Group: pitchblende cementing quartz grains in sandstone and as yet unidentified thorium-uranium minerals occurring in certain conglomerates. Thorium in the latter is probably of detrital origin.

Subeconomic and apparently discontinuous occurrences of oxide-silicate facies iron formation are also present in the area. Visual estimates of magnetite content range from 5 to 30 percent. A single analysis gave 24.8 percent total Fe, but much of the iron may be contained in iron silicate minerals.

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